

(12) **UK Patent Application** (19) **GB** (11) **2 258 274** (13) **A**  
(43) Date of A publication 03.02.1993

(21) Application No 9215243.8

(22) Date of filing 17.07.1992

(30) Priority data  
(31) 03178191 (32) 18.07.1991 (33) JP

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(51) INT CL<sup>5</sup>  
F16C 33/30

(52) UK CL (Edition L)  
F2A AD38 A111 A170 A171

(56) Documents cited  
GB 2244103 A US 4930909 A US 4904094 A

(58) Field of search  
UK CL (Edition K) F2A AD38 AD54 AD56 AD66  
INT CL<sup>5</sup> F16C

(54) Rolling bearing

(57) In a rolling bearing, at least one of the races and rolling members is made of an alloy steel that has a residual austenite content ( $\gamma_R$ ) of 20-45 vol% and which contains 1-3 wt% Cr, and Mo in an amount ranging from one third of the Cr addition to 2.0 wt%, with the carburized or carbonitrided rolling surface having the following range of Vickers hardness ( $H_v$ ) in relation to the residual austenite content:

$$-4.7 \times (\gamma_R \text{ vol\%}) + 920 \leq H_v \leq -4.7 \times (\gamma_R \text{ vol\%}) + 1,020$$

The rolling surfaces contain fine-grained carbides and carbonitrides of average particle size 0.5-1.5 $\mu$ m, and occupying 10-30% by area.

GB 2 258 274 A

FIG. 1

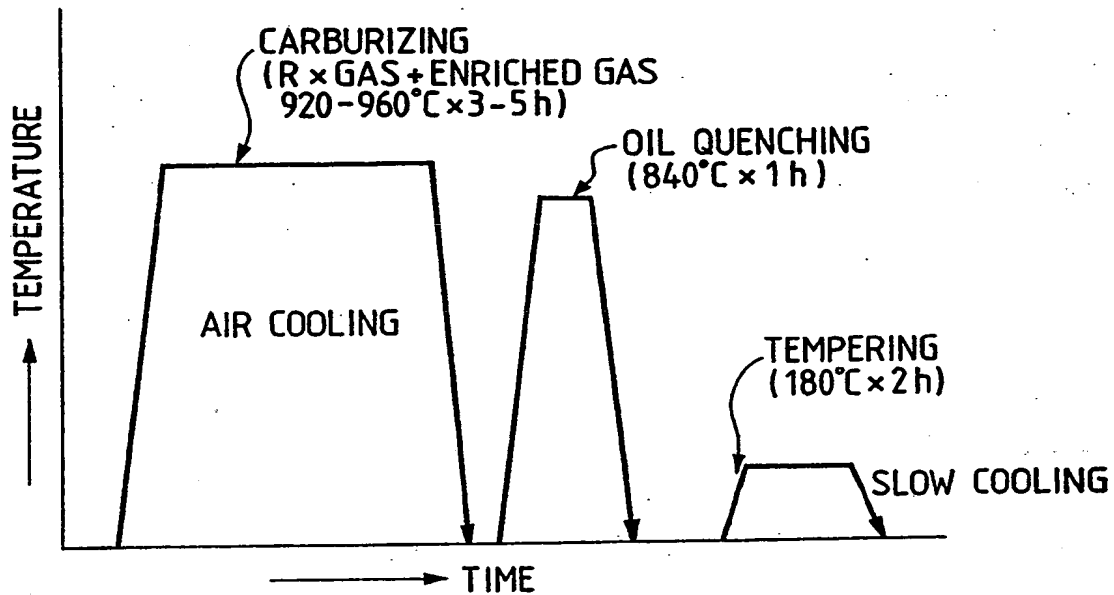
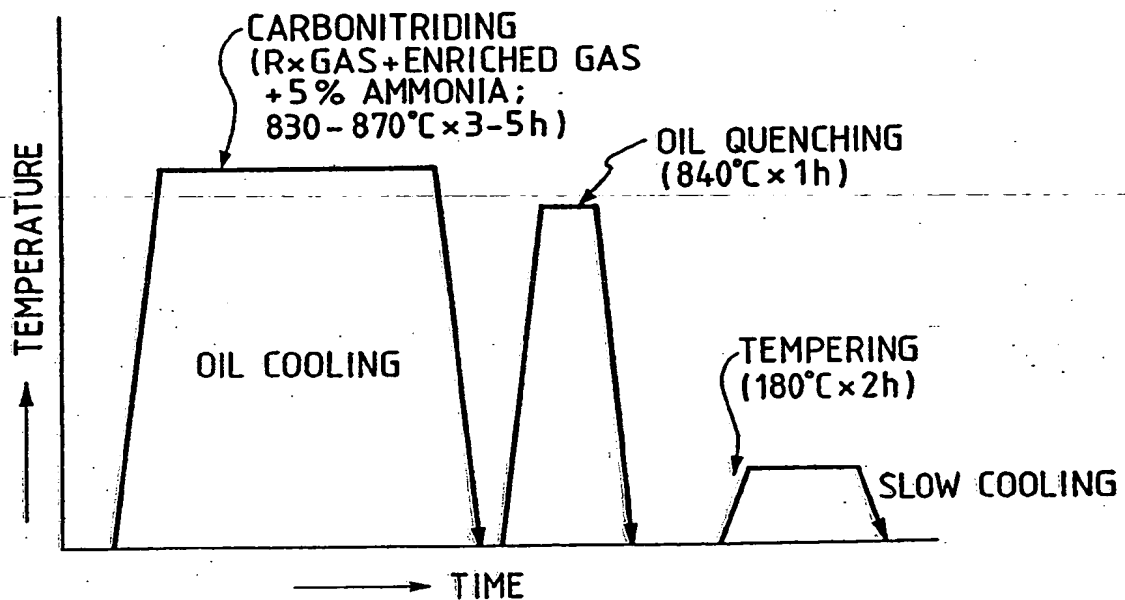


FIG. 2



## Ball and Roller Bearing

### Background of the Invention

#### Field of Industrial Utility

The present invention relates to a ball-and-roller bearing, more particularly to the improvement of the life of ball-and-roller bearings that are to be used in transmissions, engines, etc., of automobiles, agricultural machines, construction machines, as well as iron- and steel-making machines.

#### Prior Art

It is well known that foreign materials such as metal cuttings, shavings, burrs and worn particles that get into lubricants for ball-and-roller bearing will damage their races and rollers, thereby causing a substantial reduction in their service life. Under the circumstances, the assignee previously filed U.S.P. 4,904,094, in which they proposed the following: if the contents of carbon, residual austenite and carbonitrides in the rolling surface layer of a ball-and-roller bearing are specified to appropriate levels, the stress concentration that will develop at edges of indentation due to a foreign material present in the lubricant for the bearing can be reduced and the occurrence of cracking can also be suppressed to improve the life of the bearing. According to this proposal, the life of the ball-and-roller bearing under lubrication in the presence

of a foreign material can be improved by insuring that residual austenite will be present in an appropriate amount. On the other hand, the proposal involves the disadvantage that the residual austenite lowers the surface hardness of the bearing, thereby reducing its fatigue resistance. In addition, the proposal did not take into account the effects on the bearing's life of the particle size of carbides and carbonitrides; in particular, large-size carbides, if they are subjected to cyclic stress, will be the start point of fatigue, leading to the occurrence of cracking and flaking but this possibility was not all considered by the proposal.

#### Summary of the Invention

The present invention has been accomplished under these circumstances.

An optimal relationship between the content of residual austenite in the rolling surface layer and its hardness is investigated and found. Further, the average particle sizes of carbides and carbonitrides in the rolling surface layer to optimal values is adjusted so as to provide a ball-and-roller bearing that had a longer life than the prior art products not only under lubrication in the presence of foreign materials but also under lubrication in clean conditions.

The bearing proposed as a first aspect of the present invention is characterized in that at least one of the races and the rollers is made of an alloy steel that contains carbide

forming elements, that has a residual austenite content ( $\gamma_R$ ) of 20-45 vol% in the rolling surface layer and that is dispersion strengthened by fine-grained carbides or carbonitrides having an average particle size of 0.5-1.5  $\mu\text{m}$  to insure that the rolling surface will have the following Vickers hardness ( $H_V$ ) in relation to the residual austenite content:

$$-4.7 \times (\gamma_R \text{ vol\%}) + 920 \leq H_V \leq -4.7 \times (\gamma_R \text{ vol\%}) + 1,020$$

where the average particle size of carbides is defined by a following equation:

$$(\text{a maximum particle size} + \text{a minimum particle size}) \times 1/2$$

However, this ball-and-roller bearing has had the problem that it is difficult to insure the formation of fine-grained carbides or carbonitrides having an average particle size of 0.5-1.5  $\mu\text{m}$  and the case has often occurred where a large-size proeutectic carbide forms locally in the surface layer, leading to a partial failure in extending the life of the bearing.

A second aspect of the present invention has been accomplished under these circumstances and has as an object providing a ball-and-roller bearing that is characterized in that fine-grained carbides and carbonitrides can be consistently formed in the actual production and that the intended amount of residual austenite and hardness can be

achieved to insure a further improvement in the life of the bearing.

This object of the present invention can be attained by a ball-and-roller bearing that comprises races and rollers, at least one of which is made of an alloy steel that has a residual austenite content ( $\gamma_R$ ) of 20-45 vol% and which contains 1-3 wt% Cr, 0.1-1.2 wt% C and Mo in an amount ranging from one third of the Cr addition to 2.0 wt%, with the carburized or carbonitrided rolling surface having the following range of Vickers hardness ( $H_V$ ) in relation to the residual austenite content:

$$-4.7 \times (\gamma_R \text{ vol\%}) + 920 \leq H_V \leq -4.7 \times (\gamma_R \text{ vol\%}) + 1,020$$

#### Brief Description of the Drawings

Fig. 1 is a diagram showing the sequence of steps for producing the ball-and-roller bearing of the present invention, together with the conditions of heat treatments for carburization; and

Fig. 2 is a diagram showing the sequence of steps for producing the ball-and-roller bearing of the present invention, together with the conditions of heat treatments for carbonitridation.

#### Detailed Description of the Embodiments

The present invention has been accomplished on the basis of the finding of the unique effect the addition of Mo

has not only on the particle size, amount and hardness of carbides or carbonitrides that form as a result of carburizing or carbonitriding 1-3% Cr containing steels but also on their residual austenite content.

Stated more specifically, the present inventors conducted intensive studies on a method for refining the carbide precipitate which would compensate for the decrease in surface hardness due to the presence of residual austenite. As a result, they found that the size of the grains or particles of the carbide precipitate could be reduced by adding Mo in an amount controlled relative to the Cr addition (this may be called the "carbide refining effect" of Mo). The carbide composition of a steel to which Cr and Mo are added simultaneously has not yet been completely identified; however, one may safely assume that as the amount of Mo increases relative to Cr, the carbide composition will shift from a cementite-base carbide ( $M_3C$ ) to an  $M_{23}C_6$ -base alloy carbide. It is known that the precipitated particles of cementite tend to grow faster than other alloy carbides in the  $\gamma$  phase during carburization or carbonitridation; hence, one may safely assume that the above-mentioned "carbide refining effect" of Mo is due to the accelerated refining of the precipitated carbide that occurs as a result of the cementite-base carbide having changed to another type of carbide. The refining of the carbide leads to the reduction of maximum particle size and, hence, to the suppression of the formation of a macrocarbide which tends to

serve as the start point of cracking; this would probably be a cause of the success of the present invention in appreciably extending the life of a ball-and-roller bearing.

It was established experimentally that carbides tended to become more refined in carbonitriding than in carburization. This would derive from the following two facts: carbonitrides (e.g.,  $\text{Fe}_3(\text{CN})$  and  $\text{Cr}_2\text{N}$ ) are more readily refined than carbides; and the temperature for carbonitriding is lower than that for carburization. In view of these facts, one may well say that carbonitridation is more desirable than carburization for the purpose of realizing consistent production of ball-and-roller bearings.

The cementite has a Vickers hardness ( $H_V$ ) of ca. 1,000-1,500 whereas  $\text{M}_{23}\text{C}_6$ -base alloy carbides have a hardness of 1,300-1,800. The very hardness of such carbides combines with the above-described refining effect of Mo and this would help extend the life of the ball-and-roller bearing.

It is essential for the purposes of the present invention to add Mo in an amount ranging from one third of the Cr addition to 2.0 wt%. In order to insure that the addition of Mo promotes the refining of carbides (inclusive of carbonitrides; the term "carbides" as it appears hereunder shall cover "carbonitrides"), Mo must be present in an amount of at least one third of the Cr addition. If this lower limit is not reached, the amount of Mo is so small relative to the Cr content that the carbide precipitate is refined only



insufficiently to extend the life of the bearing by a desired degree. If the Mo content exceeds 2% in the presence of 3% Cr, unmelted macrocarbides such as MoC may possibly appear in the melting step; at the same time, the quenching temperature need be as high as 900°C or above but this is not preferred from the viewpoint of production efficiency.

The alloy steel of which the ball-and-roller bearing is made must possess other characteristic values and their criticality is described below.

- (i) The content of residual austenite ( $\gamma_R$ ) in the rolling surface layer: 20-45 vol%

Foreign materials in the lubricant will produce an indentation on the rolling surface layer. Cracking that tends to develop at edges of the indentation is closely related to the residual austenite. The nature of the residual austenite varies somewhat with the carbon content of the starting feed of the steel but it is usually soft and viscous. Hence, by permitting the residual austenite to be present in the rolling surface layer in a desired proportion, the stress concentration at edges of the indentation can be reduced, thereby suppressing the occurrence of cracking. The residual austenite in the rolling surface layer has another effect: if a member that passes over the indentation during rolling (e.g., the races in relation to rollers) undergoes a certain number of passes that exceeds a predetermined value, the deforming energy that is exerted on the surface will cause martensite transformation,

which hardens the rolling surface to thereby improve the life of the ball-and-roller bearing under lubrication in the presence of foreign matter. To insure that these effects are exhibited to the fullest extent, the residual austenite must be present in the rolling surface layer in an amount of 20-45 vol%.

If the content of residual austenite is less than 20 vol%, its effectiveness in reducing the stress concentration due to the occurrence of indentation by dust particles cannot be fully exhibited. If the content of residual austenite exceeds 45 vol%, its effectiveness in reducing the stress concentration is saturated and the surface hardness is reduced, rather than improved, whereby the fatigue resistance of the bearing is deteriorated. For these reasons, the content of residual austenite in the rolling surface layer must be in the range of 20-45 vol%, with the range of 25-40 vol% being preferred.

- (ii) Average particle size of fine-grained carbides and/or carbonitrides in the rolling surface layer: 0.5-1.5  $\mu\text{m}$

The surface hardness ( $H_v$ ) decreases as the content of residual austenite ( $\gamma_R$ ) in the rolling surface layer increases.

Hence, the present invention enables the surface hardness of a ball-and-roller bearing to be improved relative to the amount of residual austenite by hardening due to the precipitation of fine-grained carbides or carbonitrides. To this end, the precipitated carbides or carbonitrides must have an average

particle size of 0.5-1.5  $\mu\text{m}$ . If their average particle size is less than 0.5  $\mu\text{m}$ , the improvement in the life of the bearing is unsatisfactory and its wear resistance will decrease. If their average particle size exceeds 1.5  $\mu\text{m}$ , the precipitated carbides or carbonitrides become the source of stress concentration and the chance of the development of cracking and flaking will increase to shorten the life of the ball-and-roller bearing.

The content of the fine-grained carbides and/or carbonitrides in the rolling surface layer is desirably in the range of 10-30% by area ratio. The area ratio is defined by a following equation:

(An area of the carbides which are disposed on a surface layer / an unit area)  $\times$  100%, where the surface layer is within a range from a front surface to 0.2 mm in depth

If the content of the carbides or carbonitrides is too small, the decrease in surface hardness in response to the increase in the content of residual austenite cannot be effectively compensated. If the content of the carbides or carbonitrides is too large, the carbides will become coarse; in addition, the amount of carbon that dissolves in the matrix will decrease to such a low level that the necessary amount of residual austenite cannot be assured. In this connection, it should be noted that the amount of the carbides or carbonitrides can be controlled by adjusting various factors such as the amount of carbide-forming elements and the tempering temperature.

The carbide-forming elements may be of any known types including Cr, Mo, V and W (W will also form nitrides). Carbonitrides are those which are formed by carbonitriding rather than carburization and they include the carbides mentioned above, as well as nitrides such as  $Fe_3(CN)$ .

Preferred carbide-forming elements include Cr and Mo. Chromium (Cr) improves the quenchability and tempering resistance of steels; it is also the carbide-forming element necessary to improve the hardness of alloy steels by precipitating fine-grained carbides. The Cr content suitable for refining the carbides that will be precipitated in the rolling surface layer is in the range of 1-3 wt%. Steels with a Cr content less than 1 wt% may be carburized or otherwise treated to increase the C content so as to enhance only the surface hardness; but then, carbide nucleation is limited and carbides tend to grow so fast as to produce macrocarbides. If the Cr content exceeds 3 wt%, macrocarbides will be crystallized already in the stage of starting feed for alloy steels and the life of the bearing will decrease on account of stress concentration. Needless to say, using more than the necessary amount of Cr is not economically advantageous. In addition, if one wants to refine macrocarbides, he has to perform a heat treatment, high-temperature quenching and other procedures for dissolving the carbides in the matrix and reprecipitating them and this only results in a lower efficiency of heat treatments.

The starting feed for alloy steels may be prepared not only by casting but also by a known technique of sintering powders. The sintering of powders is a preferred method since neither macrocarbides nor carbonitrides will be crystallized in the stage of sintered feed.

For the criticality of Mo, see the related description already made herein.

Other carbide-forming elements that can be used in the present invention include V ( $\leq 7$  wt%, particularly  $\leq 3$  wt%), W ( $\leq 15.0$  wt%), or to improve a hardenability, Mn ( $\leq 2$  wt%) and Ni ( $\leq 3$  wt%) and one or more of these elements may be contained as required. If desired, annealing for spheroidization may be performed to precipitate fine-grained carbides.

(iii) Hardness ( $H_v$ ) of the rolling surface layer in relation to its residual austenite content:

$$-4.7 \times (\gamma_R \text{ vol}\%) + 920 \leq H_v \leq -4.7 \times (\gamma_R \text{ vol}\%) + 1,020$$

In accordance with the present invention, the Vickers hardness of the rolling surface layer as it relates to various amounts of residual austenite is specified to lie within the range represented by the above formula. If the Vickers hardness of the rolling surface layer is less than the lower limit of the formula, the fatigue resistance of the bearing decreases and its life is shorted irrespective of whether lubrication is effected in the presence of foreign matter in

the lubricant or under a clean condition. On the other hand, it is practically difficult to make the Vickers hardness of the rolling surface layer greater than the upper limit.

Alloy steels that can be used in the present invention include a case-hardening steel, a high-carbon chromium bearing steel and a high-speed steel for use in bearings at high temperature. The carbon content of these alloy steels is preferably in the range of 0.1-1.0 wt%. The lower limit of the carbon content is set at 0.1 wt% since it is difficult to further reduce the carbon content by the steel making technology available today. On the other hand, if the carbon content exceeds 1.2 wt%, macrocarbides tend to form already in the stage of starting feed and there is a high potential for the lowering of toughness and breaking strength. Hence, the upper limit of the carbon content of the alloy steel is preferably set to 1.2 wt%.

#### Examples

Examples of the present invention are described below.

Test samples made of steels having the compositions listed in Table 1 were heat-treated for carburization or carbonitriding.

Table 1

Sample No.	Main Components (wt%)					Heat Treatment	Residual Austenite (%)	Surface Hardness (Hv)	Carbide Average Size (μm)	Carbide Maximum Size (μm)	Life L <sub>10</sub> (x 10 <sup>6</sup> cycles)
	C	Si	Mn	Cr	Mo						
Inven- tion	1	0.32	0.35	0.60	2.95	1.55	21	890	0.7	2.1	9.1
	2	0.85	0.40	0.50	1.80	0.98	35	806	0.7	1.6	10.5
	3	0.43	1.02	0.45	1.55	0.65	30	856	0.7	1.5	15.1
	4	0.62	0.25	1.21	2.40	1.10	25	865	0.5	2.2	11.0
	5	0.19	0.26	0.73	2.10	0.75	33	832	0.6	2.3	21.2
Compari- son	6	0.42	0.25	1.09	2.71	0.36	27	806	0.8	8.6	5.0
	7	0.35	0.30	0.61	1.56	0.36	28	795	0.7	6.8	4.1
	8	0.20	0.28	0.65	2.41	0.42	26	801	1.2	7.5	3.9
	9	0.62	0.25	0.63	2.17	0.30	35	758	1.4	6.3	3.6
	10	0.36	0.25	0.45	2.99	0.50	20	855	0.7	6.5	5.1
	11	0.42	0.25	1.09	2.71	0.36	25	783	2.2	10.5	1.5
	12	0.42	0.25	1.09	2.71	0.36	30	689	0.2	12.5	1.6
	13	0.42	0.25	1.09	2.71	0.36	33	724	2.9	7.8	2.1
	14	0.42	0.25	1.09	2.71	0.36	38	671	0.4	9.0	1.7
	15	0.42	0.25	1.09	2.71	0.36	46	687	1.3	9.6	3.0
	16	0.30	0.28	0.61	1.35	0.01	14	760	1.2	2.5	1.0
	17	0.26	0.28	0.65	2.33	0.02	12	765	1.5	6.8	1.2
	18	0.61	0.25	0.50	2.70	0.01	45	657	1.5	7.5	2.1
	19	0.33	0.25	0.45	3.10	0.02	30	743	1.3	8.0	1.5
	20	0.38	0.27	0.46	2.86	2.05	22	905	0.8	5.9	6.2
	21	0.41	0.25	0.51	0.92	1.08	30	740	0.7	6.8	4.1

Of the two methods of heat treatment employed, direct quenching for carburization consisted of the following steps (see Fig. 1): heating in an (Rx gas + enriched gas) atmosphere at 920-960°C for ca. 3-5 h; air cooling to ambient temperature; oil quenching at 840°C x 1 h; and tempering at 180°C x 2 h. Carbonitriding consisted of the following steps (see Fig. 2): heating in an (Rx gas + enriched gas + 5% ammonia gas) atmosphere at 880°C for ca. 3-5 h; oil cooling to ambient temperature; the same subsequent treatments as in carburization.

The thus treated test samples were measured for the content of residual austenite, surface hardness, the average particle size of carbides and their maximum particle size. The average particle size of carbides is defined by a following equation:

$(d_{\max} + d_{\min}) \times 1/2$ , where  $d_{\max}$  means a maximum particle size and  $d_{\min}$  means a minimum particle size in the surface layer (which is within a range from a front surface to 0.2 mm in depth).

The residual austenite content was measured by X-ray analysis whereas the particle size of carbides was measured by a microscopic method.

The treated test samples were also shaped into disk-shaped specimens suitable for use not only as the inner race but also as the outer race of a ball-and-roller bearing and subjected to a thrust life test with a thrust bearing steel



testing machine of the type described in "Tokushuko Binran (Handbook of Specialty Steels)", First Edition, compiled by Denki Seiko Kenkyusho, published by Rikogakusha, May 25, 1969, pp. 10-21. The testing conditions were as follows:

N = 1,000 rpm

Pmax = 500 kgf/mm<sup>2</sup>

Lubricant = Turbine oil No. 68

Steel particles (Fe<sub>3</sub>C with H<sub>v</sub> of 870 and a diameter of 74-147 μm) were added to the lubricant as dust particles in an amount of 300 ppm.

The point of time when cracking or flaking discernible with a microscope or the naked eye developed in 10% of the specimens of each test sample was designated the life (L<sub>10</sub> life) of that sample and the cumulative number of revolutions to that point was used as a quantitative means of expressing the life.

The test results are also shown in Table 1, in which sample Nos. 1-5 correspond to examples of the second aspect of the present invention, with the amounts of Cr and Mo addition being within the range specified by claim 1. Sample Nos. 6-19 are comparative samples; sample Nos. 6-10 were within the scope of the first aspect of the present invention but the amount of Mo addition was less than a third of the Cr addition and, hence, was smaller than the lower limit of the range specified by the present invention; the amount of Mo addition to sample Nos. 11-15 was also less than a third of the Cr addition and

their surface hardness was outside the scope of the present invention; sample Nos. 16-19 were outside the scope of the present invention in terms of any of the Mo addition, the residual austenite content and the surface hardness. In the sample No. 20, Mo in the main components is more than 2wt%, so that it is not

As is clear from Table 1, sample Nos. 1-5 prepared in accordance with the second aspect of the present invention were equivalent to one another in that the particle size of carbides, in particular, their maximum size, was noticeably smaller than in the case of the comparative samples, and the effectiveness of Mo in extending the life of bearing was marked.

Sample Nos. 6-10, which are in a range of the subject matter of GB 2244103 A (Not prior art) filed by the same applicant, were comparable to sample Nos. 1-5 of the present invention as regards the average particle size of carbides but their maximum particle size was considerably larger than that of sample Nos. 1-5. Their life was no longer than one half to a third of the life of sample Nos. 1-5. Comparative sample Nos. 11-15 varied greatly in the average particle size of carbides and their maximum particle size was also much greater than in the case of sample Nos. 1-5. The life of comparative sample Nos. 11-15 was even shorter than that of sample Nos. 6-10. Comparative sample Nos. 16-19 had such a tendency that the maximum particle size of carbides was smaller than that of

sample Nos. 11-15 and yet the average particle size of carbides in sample Nos. 16-19 was fairly large and those samples had the shortest life. Comparative sample No. 20, wherein the content of Mo is more than 2.0 wt%, formed MoC so that a carbide of extremely large particle size which is immiscible in the matrix was easily formed, thereby its life was shorter. Comparative sample No. 21, wherein the content of Cr is less than 1.0 wt%, Cr easily form a carbide of extremely large particle size with the carbon atom. Further, since the content of Cr which is an element to form carbides is small, Comparative Sample No. 21 was inferior in the surface hardness, so that its life was shorter.

As examples of the present invention, only sample Nos. 1-5 made of steels having the compositions listed in Table 1 were used but these are given merely for an illustrative purpose and steels of other compositions may be used.

In the examples of the present invention, gas carburization was performed but this is not the sole case of the invention and ion carburization may be adopted as a carburization technique.

As described on the foregoing pages, the present invention promotes the refining of carbide particles by controlling the amount of Mo addition to be within the specified range in relation to the amount of Cr addition. This offers the advantage of providing a ball-and-roller bearing

that has a long life even if it is used for lubrication in the presence of foreign materials.

While the present invention has been described above with respect to a single preferred embodiment thereof, it should of course be understood that the present invention should not be limited only to this embodiment but various change or modification may be made without departure from the scope of the present invention as defined by the appended claims.

CLAIMS

1. A ball-and-roller bearing comprising races and rollers of which one or both comprises an alloy steel containing 0.1 to 1.2 wt% C, 1 to 3 wt% Cr, and Mo in an amount from one-third of the amount of Cr to 2.0 wt%, the alloy steel being as obtained by carburizing or carbonitriding, quenching and tempering, such that its rolling surface has a residual austenite content ( $\gamma_R$ ) of 20 to 45 vol% and a Vickers hardness ( $H_v$ ) satisfying the equation:
- 10 
$$920 \leq H_v + 4.7\gamma_R \leq 1020$$
2. A bearing according to claim 1, wherein the rolling surface contains carbides and/or carbonitrides having a particle size of 0.5 to 1.5  $\mu\text{m}$ .
3. A bearing according to claim 1 or claim 2, wherein the rolling surface contains 10 to 30% by area of particulate carbides and/or carbonitrides.
- 15 4. A bearing according to claim 1, substantially as exemplified herein.

## Search Examiner

B B CASWELL

**Date of Search**

15 SEPTEMBER 1992

(ii)

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